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## Engineering Design Challenges in a Science Curriculum

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Create a light and sound show to entertain your friends. Design an improved safety device for a car. Develop a 2-3 minute voice-over for a sports clip explaining the physics involved in the sport. Modify the design of a roller coaster to meet the needs of a specific group of riders. Design an appliance package for a family limited by the power and energy of wind generator. Develop a museum exhibit to acquaint visitors with the atom and nucleus and create a product that can be sold at the museum store after visitors leave your exhibit.

All of these challenges are part of *Active Physics* (2005), a high school curriculum developed with support from NSF, field tested with thousands of students and presently used across the country. The challenges (mentioned above) serve as a framing structure for the required science content. Each chapter (approximately five weeks of instruction) is introduced by way of a chapter challenge. The students upon hearing the challenge at first react with silence. We originally thought that the students' silence indicated interest – a rapt awe. Upon interviewing, we found out that the students were in shock. How can they possibly succeed at such a challenge? The sports voice-over or light show or museum exhibit interested them, but their lack of knowledge surrounding the science content suppressed any enthusiasm that they might have for the topic. After the first months of school, with some success at the chapter challenges, the students approached the next challenge with cautious confidence that they would be able to learn the science content and could then use their creativity to complete the challenge.

In this brief paper, I will outline the ways in which the chapter challenge is introduced, revisited and then completed. Included in the discussion will be how the chapter challenges are chosen, how we scaffold students' learning so that they can be successful and the benefits of the chapter challenge. *Active Physics* is neither an engineering course nor a technology course. It uses engineering design as a way in which students can approach their chapter challenge, but engineering design must remain in the background of the physics content and curriculum.

After being introduced to the chapter challenge on day one, students are then asked to imagine what a successful project will include. This requires them to set criteria for excellence that not only includes "correct physics content" but may also include creativity, adherence to the time limits, safety considerations, presentation skills and involvement of all members of the group. Students generate this list and the teacher helps students decide on an initial weighting of these different factors for a final grade. Since the students have not yet learned the required physics content, they are assured that they will revisit their grading rubric once the chapter is completed and prior to beginning work on their challenge. After completing their grading rubric, students can then compare their rubric

with the one presented in the book. Having them complete the rubric on their own leads to a much more productive reading of the book's suggested rubric. Students feel a sense of pride when they match most of the factors that are presented in the text. They also are able to read the text's criteria with a better understanding having given the criteria some initial thought.

At this point, they are also introduced to an "Engineering Design Cycle." The elements of the cycle are described to the students:

- Goal
  - Define the problem
  - Identify available resources
  - Draft potential solutions
  - List constraints to possible actions
- Inputs
  - Complete the investigations in each section
  - Learn new physics concepts and vocabulary
- Process
  - Evaluate work to date
  - Compare and contrast methods and ideas
  - Examine possible trade-offs to help reach goals and maximize efforts
  - Create a model from your information
  - Design experiments to test ideas and the suitability of the model
- Outputs
  - Present *Mini-Challenge* and intermediary steps or products
  - Present *Chapter Challenge* based on feedback from the *Mini-Challenge*
- *Feedback*
  - Obtain response from target audience leading to modification of the goal
  - Identify additional constraints, requiring restarting the input and process stages

After students complete each section (approximately three days of instruction), they are asked to "Reflect on the Section and the Challenge." This helps remind them of why they are learning this physics content (i.e. "I need this content to complete the challenge.") It also provides a formative assessment in which they get to transfer the knowledge from their investigations to a new domain – the chapter challenge.

Midway through the chapter, the students complete a Mini-Challenge. The students are re-introduced to the Engineering Design Cycle. They are better able to understand this cycle at this point because they have now completed half the sections of the chapter and are well aware of the "inputs" that can be used in the "process" and "outputs" phases. They are reminded of the goals for the chapter challenge and asked to review the criteria that they set for success. They are reminded that they have more to learn in this chapter which will help them with the chapter challenge, but that this is a good time to give the Chapter Challenge a first try. This first try gives the students a good sense of what the challenge entails and how they and their teams may approach completion of the challenge. They are

then reminded of the sections (and physics concepts) that they have completed. They are also given specific instructions as to how to bridge the physics concepts to the completion of this mini-challenge. This is the process stage that they undertake for one class period. Each team presents their work to the entire class as the “outputs” phase of the mini-challenge. Finally, the teams receive “feedback” from the other teams and the teacher. The “feedback” from the mini-challenge will become additional “input” for the final design in the Chapter Challenge.

The Mini-Challenge serves a number of distinct purposes. As mentioned, it gives the students a sense of what the challenge entails. The presentation of their Mini-Challenge makes students aware of what is working well and what should be altered in their approach. The presentations also allow teams to see what other teams are doing. This provides them with new ideas for their chapter challenge. It also provides peer pressure for some teams to ratchet up their effort to match the efforts of other teams.

After the Mini-Challenge, the students complete the remaining sections in the chapter. Once again, each section concludes with an opportunity for students to “reflect on the section and the challenge.” Each section continues to broaden the knowledge that they can bring to the chapter challenge.

The chapter concludes with the final exposure to the Engineering Design Cycle. In a two-page spread, students are once again led through the cycle and given some hints and suggestions for how to navigate the “process” and “outputs” phase and reminded of the feedback that they will both give and receive.

The presentations of the chapter challenge have a number of distinct benefits. In preparing for the chapter challenge, students must transfer their knowledge of physics concepts to the task at hand. Research has shown that transfer is an important component of learning. Learning takes place during the transfer. The students must apply what they have learned to a new domain. It also serves as purposeful learning. A student may want to describe the path of a football and may only then realize that her knowledge about the physics of the motion is tenuous. Now is the opportunity for this student and the team to review that section with the specific goal of using this information in their chapter challenge.

The chapter challenge also provides motivation. It has been well documented that student motivation positively impacts learning. We may expect that students will display pride in knowing the equations for the conservation of momentum, but the real pride comes from each student team finding creative ways in which to communicate momentum conservation. In the execution of the chapter challenges, students have the opportunity to choose something that interests them. In the sports voice-overdub, student teams decide which sport will be theirs. Many teachers expand the definition of sport to any physical activity so that a student team can include ballet or break-dancing. One teacher suggested that a team of girls who were consumed by the fashion world may want to explain the physics of runway strutting. The point is that different teams have a choice of what interests them in their choice of how to complete the chapter challenge.

The students also gain a level of “expertness.” In a sports voice-over challenge, all students in the class will understand and be able to solve problems using Newton’s 2<sup>nd</sup> Law. One student team will become “expert” at applications of Newton’s 2<sup>nd</sup> Law to baseball while other teams will become “expert” at applications of Newton’s 2<sup>nd</sup> Law to lacrosse, soccer, swimming or volleyball. Being an expert also contributes to engaging students intellectually.

The chapter challenges also provide an opportunity for students to promote their culture and their interests in the classroom. We live in a wonderfully diverse nation. In some schools and classrooms, students speak more than twenty languages. Teachers are often told that it will be beneficial to bring a student’s culture into the classroom. How is this possible? When a new student comes into class from Nicaragua, is a science teacher supposed to read a book about Nicaragua and pretend to be an expert? In one challenge, students are required to create a light and sound show. This light and sound show will certainly reflect the interests and cultures of the students. One student group may use Latino music, while another may use rap, a third may use African folk tunes, and another may use hip-hop. The student groups are able to bring to the chapter challenge their interests and their cultures. We can then respect, celebrate, and honor those cultures.

Finally, the presentation of the chapter challenge provides a meaningful review of the physics concepts of that chapter. The review is not conducted by the teacher, but rather by each team during the presentation. Since each team chooses their own sport or creates their own museum display or presents their own light and sound show, the entire class learns about the physics concepts in several different contexts. Each team contributes a new context in which to view the physics concepts.

The criteria for choosing the chapter challenges include student interest, breadth of physics concepts, ability to grade, and opportunity for original, unique outputs. Ideas for chapter challenges that would engage high school students were generated by a group of physicists and physics educators that fell within certain large topic areas – sports, medicine, transportation, communications, energy and home. (Some of these coincide with broad technology fields.) Each chapter challenge had to be rich enough in physics concepts to require approximately one month of instruction. Displaying mastery of the physics content had to be a requirement for completion of the challenge. After we converged on the first challenge, we realized that we needed to find a way in which to grade the challenge. This led us to the idea of creating a grading rubric which then led us to the idea of having the students create the grading rubric. Since this work was done in 1993, grading rubrics had not yet emerged as an important consideration in school instruction.

In imagining what students may create for their design, we insisted that all teams would not have identical outputs. For example, in many physics courses the analysis of a roller coaster is the vehicle for introducing, explaining and then testing for an understanding of energy conservation. Designing a roller coaster was an obvious choice for a chapter challenge. In creating a chapter challenge regarding the design of a roller coaster, we were surprised that real roller coasters are not entertaining because of energy conservation but

because of forces. The chapter had to straddle the content of energy conservation and forces for it to include important physics concepts and to be relevant. We also realized that in many classes, all students analyze the same roller coaster and all get identical answers. We wanted to engage students and have them design unique roller coasters. We therefore added the additional constraint that students have to design their roller coaster for a specific population – thrill seeking daredevils, elderly people, young children, or physically challenged people. This additional constraint adds to student engagement (i.e. they choose the riders) and allows for radically different designs of roller coasters. Finally, high school students were surveyed about their interest in these challenges. These surveys forced us to table some of our ideas and led to challenges which had inherent interest for our target population.

In using engineering design challenges in *Active Physics* as well as in *Active Chemistry*, we have promoted an engineering perspective, introduced the engineering design cycle and used engineering vocabulary in high school science classes. We review the engineering design at multiple times in each chapter – at the introduction, at the mini-challenge and at the chapter challenge. We also remind students of the need to connect their new physics concepts to the chapter challenge after each of the ten sections per chapter. These are physics and chemistry courses. Most state frameworks in science do not mention any of these engineering design principles nor do any of the state exams in science ask students to demonstrate their knowledge of these principles. We have found that these chapter challenges are a motivating addition to the science curriculum and can be effectively added to the curriculum. We view these as a necessary component of our programs and recognize that learning will be diminished without them.

### References

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